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OPTIMIZATION OF FRICTION STIR WELDING PARAMETERS TO IMPROVE THE MECHANICAL PROPERTIES OF DISSIMILAR AA2024 AND AA6061 ALUMINIUM ALLOYS

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ABSTRACT

Friction Stir Welding (FSW) is a solid state welding process widely used for joining of similar and dissimilar metals for various engineering applications. AA2024 AND AA6061 plates of 6mm thickness were joined by using non-consumable tapered (semi-conical) twin pin tool. The wedding parameters considered for this study are tool rotational speed, welding speed and tool tilt angle at three levels, experiments were conducted as per Taguchi's L27 orthogonal array. By varying welding parameters defect free welding joints were produced later ANOVA analysis was carried out to investigate the percentage of contribution of parameters to improve the mechanical properties.

KEYWORDS: Friction Stir Welding, Optimisation, Taguchi Method, Twin-Pin Tool & ANNOVA Analysis

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Original Article

INTRODUCTION

Nowadays it is difficult to join aluminum alloys by using fusion welding. It is difficult because of variation in chemical composition and mechanical properties. Friction stir welding offers an efficient solution to this challenging task, but it is difficult to weld with other methods due to the present of oxide layers forming on them. K. Colligan et al explain about the advantage of friction stir welding (FSW) in aluminum alloys when compared to other methods is the technique used by non-consumable rotating tool to produce frictional heat and plastic deformation in the direction of the weld.

Friction Stir Welding is a welding method including friction welding where the process required no filler material or additional heat generation to melt the metal because by the friction of the rotating tool with the stationary workpiece. Ch. Ratnam et al studied the effect of twin pin tool to improve weld quality. The tool material should be strong, hard and have heat conductivity in order to protect the welding machine from damage. Since tool geometry plays a major role in dissimilar welds, several tool profiles are in welding being used for pin profiles such as threaded; square, tapered and triangular are used to transfer the material from front side to back side of the tool by stirring action.

Wayne M. Thomas et al studied the developments in friction stir welding by implementing Re-stir technique may well become the preferred option for certain butt and lap weld configurations. W.H.Jiang et al

reported that Friction stir welding is a feasible route for joining aluminum and steel dissimilar metals. The weld joint has a good weld quality and sound welds. The tensile failure happened in the middle zone and indicating that weld has a high joining strength.

D.M. Rodrigues et al studied the influence of friction stir welding parameters on1mm thin plates of AA 6016-T4 aluminum alloy with conical and scroll shoulders and concluded that the difference in tool geometry and weld parameters induced significant changes in the material flow path during welding. The welds produced with conical shoulder displayed a larger nugget grain size with few coarsened precipitates as opposed to the weld done with the scrolled shoulder, which showed a smaller grain size containing many coarsened precipitates this difference in microstructure shows in a reduction in hardness in welds prepare by the scrolled shoulder.

P. Cavaliere et al studied the mechanical and microstructural behavior of dissimilar friction stir welding AA6082-AA2024. The joints were produced with different alloy positioned on the advancing side of the tool and concluded that the best tensile and fatigue properties were obtained for the joints with soft metal AA6082 on the advancing side and concluded the welding speed does not influence the fatigue behavior so strongly

J.C. Hou et al Investigated the effect of rotation speed with a specially designed tool with unequal shoulder diameters at a constant welding speed and concluded that the grain side and the dislocation density in the weld zugget zone increased with increasing rotation speed. The tensile strength of joint first increases with increasing rotating speed and then decreased remarkably as a result of the formation of the void defect. Rusdi Mur et.al. studied the effect of welding parameters on Friction Stir Welding with shoulder diameter welding speed and tool profile and analysed the mechanical properties of tensile and bending strengths that the tool with a shoulder diameter of 17.8 mm will give highest tensile strength at 1300 rpm and feed rate of 50mm/min at 221.1MPa and highest bending strength at 1300 rpm with a feed of 20.8 mm/min at 422.6MPa.

S.Amini et at Used various tool profiles to perform Friction Stir Welding of AA5083 and found that the tool temperature for tools with half pin and arched pin had a significant increase with the increase of rotational speed. The tools with more mixing ability and forging of transferred motion from front to back of the tool pin shows more tensile strength. K.Sunil Ratna Kumar et al studied the optimization of parameters through the taguchi technique and analyzed the parameters to show the percentage contribution.

K.Dehghani et al performed the friction stir welding for AA7075-O to study the effect of mechanical and microstructure properties. He found that the size and distribution of precipitates are second phases are relatively coarse in the HAZ and finer in the stirred zone. Hardness and strength of stirred zone were increased for its ductility; the maximum hardness was obtained at the stirred zone whereas lowest at its base metal. The strength of the weldments was achieved by changing coarse particles on to fine grains in precipitation process but bending strength is lower at the weld zone due to the formation of cracks.

From the thorough research literature on different tool profiles, the following semi-cylindrical tool is adopted for the current research, which is shown in the below figure 1.

Figure 1: Semi-Cylindrical Twin-Pin Tool used for Current Experiments

EXPERIMENTAL PROCEDURE

The materials used in this study are AA2024 alloy (Al-Cu alloy) and AA6061 alloy (Al-Mg-Si alloy), the chemical compositions and mechanical properties for 2024 and 6061 are shown in below table 1.

Table 1: Chemical Composition of AA2024 and AA6061 Alloys (wt%)

Component	AA2024	AA6061
Cr	0.1	0.35
Cu	4.9	0.4
Fe	0.5	0.7
Mg	1.8	1.2
Mn	0.9	0.15
Si	0.5	0.8
Ti	0.15	0.15
Zn	0.25	0.25

The aluminum plates were cut into rectangular shapes of 100X50X6 mm and Friction Stir Welding was carried out using a vertical milling machine. The welding tool used in this study was HCHCR steel, with semi-conical twin-pin profile having shoulder diameter of 20mm and pin diameter of 6mm. The process parameters are considered in three levels each as shown in table 2.

Table 2: Considered Process Parameters and their Levels for Investigation

Parameters	Level 1	Level 2	Level 3
Tool rotational speed (rpm)	1130	1340	2000
Welding Speed (mm/min)	11	18	22
Tilt angle (degrees)	1	2	3

AA2024 was placed on the advancing side due to high mechanical properties and AA6061 is placed in retreating side, the L27 orthogonal array Taguchi's method was used to find the design of experiments later ANOVA analysis was carried out to determine the percentage contribution of each input parameters. The schematic FSW operation of the dissimilar AA2024 and AA6061 are performed on a vertical milling machine shown in figure 2.

Figure 2: Slightly Modified CNC Milling Machine Setup Used for the Experiment

The welded specimens were cut according to the ASTM E8 standard and tensile tests were performed using the universal testing machine with a constant speed in room temperature to evaluate tensile strength of weld joints for analysis. Later Viker's Hardness tests were carried out and the average value is considered for analysis.

Table 3: Process Parameters with Test Results

S. No	Tool Rotational Speed, rpm	Welding Speed, mm/min	Tool Tilt Angle, Degree	Tensile Strength, N/mm²	Average Hardness Value, VH
1	1130	11	1	297.5	86.92
2	1130	18	1	282.5	84.14
3	1130	22	1	285.2	80.24
4	1130	11	2	306.9	76.58
5	1130	18	2	290.3	79.81
6	1130	22	2	300.9	77.72
7	1130	11	3	293.3	83.98
8	1130	18	3	280	79.23
9	1130	22	3	305	78.07
10	1340	11	1	309.4	76.08
11	1340	18	1	311.55	76.94
12	1340	22	1	285	73.12
13	1340	11	2	313.05	73.82
14	1340	18	2	315.23	73.72
15	1340	22	2	282.5	74.49
16	1340	11	3	299	74.77
17	1340	18	3	286.6	76.32
18	1340	22	3	286	76.14
19	2000	11	1	282.5	76.19
20	2000	18	1	303	77.12
21	2000	22	1	280.2	75.92
22	2000	11	2	281.6	87.54
23	2000	18	2	296.8	81.89
24	2000	22	2	294.7	85.37
25	2000	11	3	280.2	88.81
26	2000	18	3	287.5	83.02
27	2000	22	3	284.4	85.21

RESULTS AND DISCUSSIONS

For the 27 specimens with all the different combinations of input parameters are used to obtain the tensile strength and are shown in the table to analysis the FSW process parameters and tensile strength values were analyzed using

Taguchi's method to find the influence of parameters, signal to noise ratios are calculated in this process, the large S/N ratio value means the better the response. Response optimization will give a better combination of input parameters. The values are calculated by using the MINITAB software and analyzed the S/N values for the combinations.

Table 4: ANOVA Table for Tensile Strength

Source	DF Adj	Sum of Squares	Mean Sum of Squares	F-Value	P-Value	Percentage
A	2	0.4428	0.22139	8.86	0.009	15.5882
B	2	0.1896	0.09479	3.79	0.069	6.67464
C	2	0.3007	0.15034	6.02	0.025	10.5857
A*B	4	1.1923	0.29807	11.93	0.002	41.9735
A*C	4	0.1711	0.04276	1.71	0.240	6.02337
B*C	4	0.3443	0.08608	3.45	0.064	12.12067
Error	8	0.1999	0.02499			7.03724
Total	**26**	**2.8406**				

From the table 4, it can be concluded that the tool rotational speed has a contribution of 15.58% and with the combination has 41.97% followed by tool tilt angle which has a contribution of 10.85% with a combination of 12.12%. Among the three parameters welding speed has the lowest percentage of 6.67% with a combination of 6.023%.

Table 5: Shows Response Table for Tensile Strength

Level	Tool Rotational Speed	Welding Speed	Tool Tilt Angle
1	49.35	49.42	49.33
2	49.50	49.38	49.48
3	49.18	49.22	49.22
Delta	0.32	0.19	0.26
Rank	1	3	2

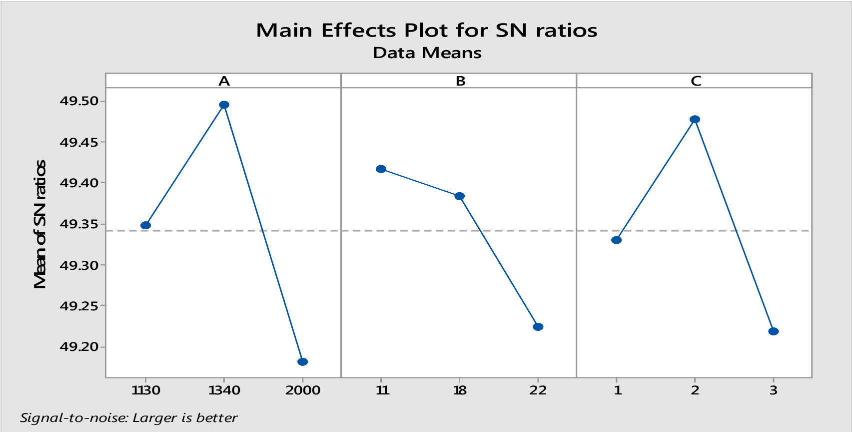

Figure 3: The Combination of S/N Ratio Values

From the table 5 and figure 3, it can be calculated that tool rotational speed of 1340 rpm, welding speed of 11mm/min and tool tilt angle of 2 degrees is the optimum welding condition to get good tensile strength.

HARDNESS

Hardness of the material is defined as the resistance to plastic deformation. We need higher hardness value to resist for deformation. Thus we use larger-the-better to calculate S/N ratio. Table 6, shows the ANOVA table for average hardness at weld zone

Table 6: ANOVA Table for Hardness

Source	DFAdj	Sum of Squares	Mean Sum of Squares	F-Value	P-Value	P.C
A	2	0.83200	0.41600	35.07	0.000	47.0067
B	2	0.05831	0.02916	2.46	0.147	3.29442
C	2	0.06815	0.03408	2.87	0.115	3.85036
A*B	4	0.06915	0.01728	1.46	0.301	3.90460
A*C	4	0.59175	0.14794	12.47	0.002	33.4329
B*C	4	0.05573	0.01393	1.17	0.391	3.14865
Error	8	0.09491	0.01186			5.36226
Total	**26**	**1.76996**				

From the table, it can be concluded that the tool rotational speed has a contribution of 47% with combination has 33.43%. It is followed by a tool tilt angle which has a contribution of 3.85% with a combination of 3.148%. Among the three parameters welding speed has the lowest percentage of 3.294% with a combination of 3.904%.

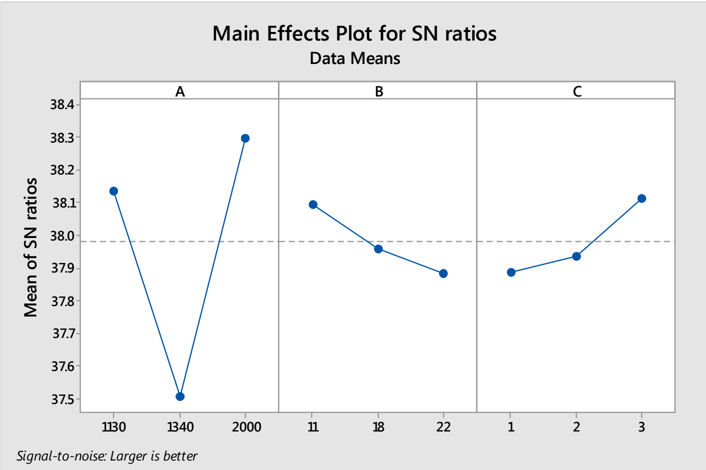

Figure 4: The Combination of S/N Ratio Values

Table 7: Shows Response Table for Hardness

Level	Tool Rotational Speed	Welding Speed	Tool Tilt Angle
1	38.14	38.10	37.89
2	37.51	37.96	37.94
3	38.30	37.88	38.11
Delta	0.79	0.21	0.23
Rank	1	3	2

From the figure 4 and the table 7, it can be concluded that tool rotational speed of 2000, welding speed of 11mm/min and tilt angle of 3 degrees is the optimum welding conditions to get good hardness at weld zone.

CONCLUSIONS

The following conclusions are drawn from the present study

- Tool rotational speed is the major factor contribution to the effect of tensile strength with 15.58% while welding speed has the least effect with 6.6745%.
- The optimum parameters to obtain good tensile strength are tool rotation speed of 1340rpm, welding speed of 11 mm/min and tool tilt angle of 2 degrees.

- Tool rotational speed is the major factor contribution to the effect of hardness at weld zone with 47% while welding speed has the least effect with 3.294%.
- The optimum parameters to obtain good hardness at weld zone are found to be tool rotational speed of 2000 rpm, welding speed of 11mm/min and tool tilt angle of 3 degrees.
- It is also proven by using twin-pin tool defect free welding joints were prepared.

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